



Fundamental Aeronautics Program

Subsonic Rotary Wing Project

Overview of Recent OVERFLOW Code Enhancements and Applications for the Subsonic Rotary Wing Project

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2012 Technical Conference
March 13-15, 2012

Outline

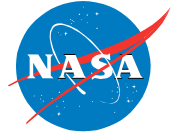


Motivation / Objective

OVERFLOW Improvements and Results

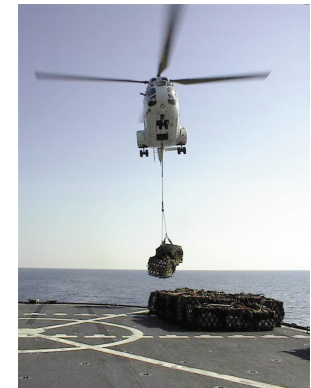
- Fuselage Drag Reduction Via Active Flow Control
- Turbulence Model Assessment for Rotorcraft Flows
- Rotorcraft Transition Modeling—Future
- Simulation of V22 Rotor System in Hover
- Simulation of UH60 Rotor System In Forward Flight
- Near Body Adaptive Mesh Refinement
- Heavy Lift Slowed-Rotor Compound Helicopter Flow Computations
- Isolated Rotorblade Flutter Computations

Motivation / Objective



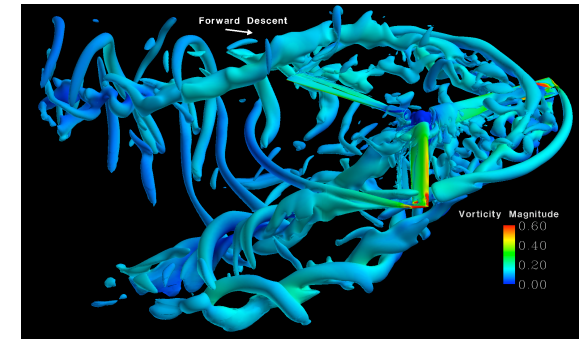
- Helicopters/Tiltrotor Aircraft Provide Many Crucial Services

- Emergency medical/rescue evacuation, security, offshore oil platforms, heavy-lift, military operations



- Challenging Phenomena Associated with Rotorcraft

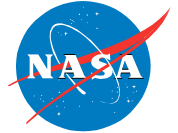
- Aerodynamic performance and noise prediction
- Vortex wakes and vortex blade interaction (BVI)
- Rotor blade flexibility and vibration
- Moving components
- Multidisciplinary (aerodynamics, structures, trim)



- Many of These Phenomena Are Poorly Understood and Difficult to Accurately Predict

- One objective of NASA's Subsonic Rotary Wing (SRW) Project is to develop physics-based computational tools to address these issues

Fuselage Drag Reduction via Active Flow Control



Problem

- Helicopter fuselage drag significantly reduces forward flight performance and must be reduced to enable high-speed flight

Objective

- Use CFD to provide guidance on design of active flow control system for fuselage drag reduction in forward flight for a mid-scale wind tunnel test

Approach

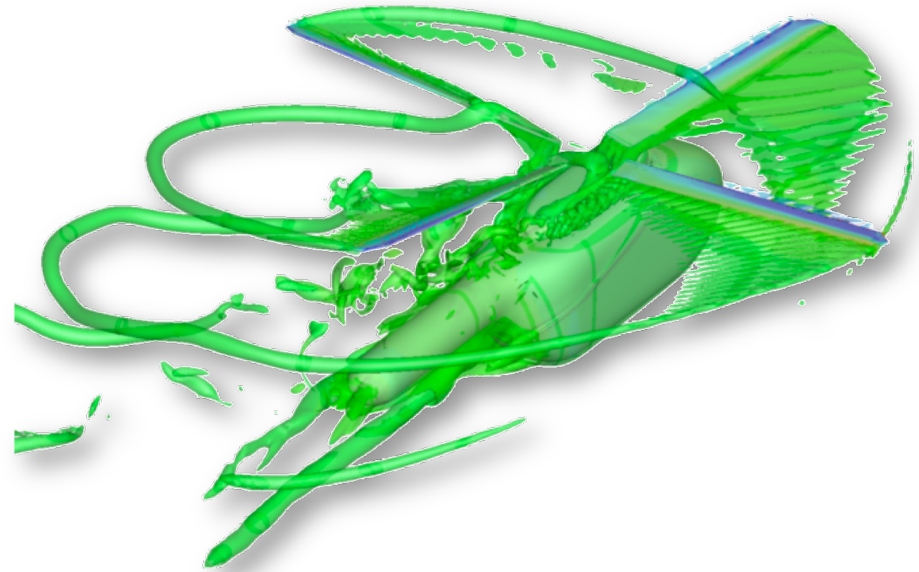
- Study placement of flow control actuators and actuator parameters using CFD
 - Generic fuselage shape (ROBIN-mod7)
 - OVERFLOW2/CAMRAD II loose coupling

Results

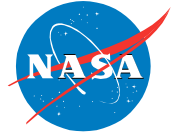
- Validated CFD using small scale isolated fuselage wind tunnel test
- Identified blowing slot locations and actuator parameters for maximum predicted fuselage drag reduction (~20% in forward flight)
- CFD also predicts maximum fuselage download reduction of 30%

Significance

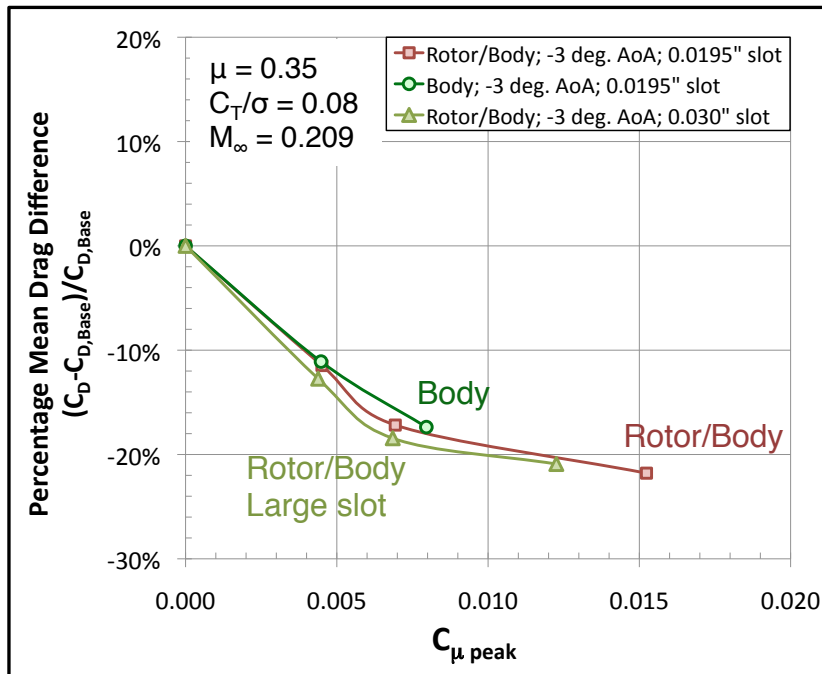
- Drag reduction with simultaneous download reduction offers potential to significantly improve helicopter performance in forward flight.
 - Drag reduction enables higher speeds
 - Download reduction allows increased payload and/or maneuver performance



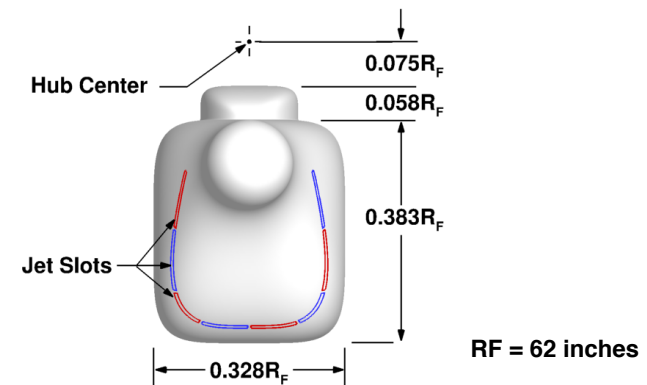
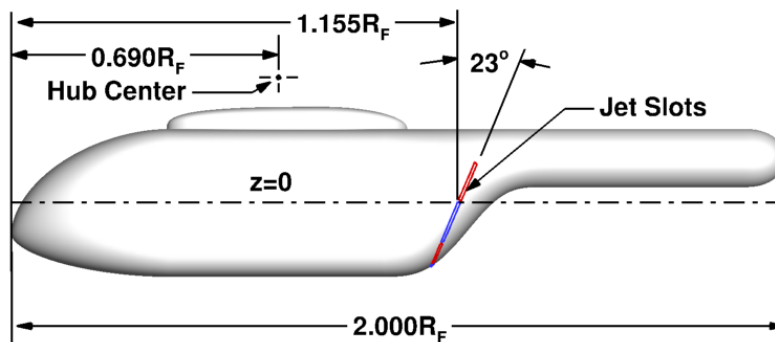
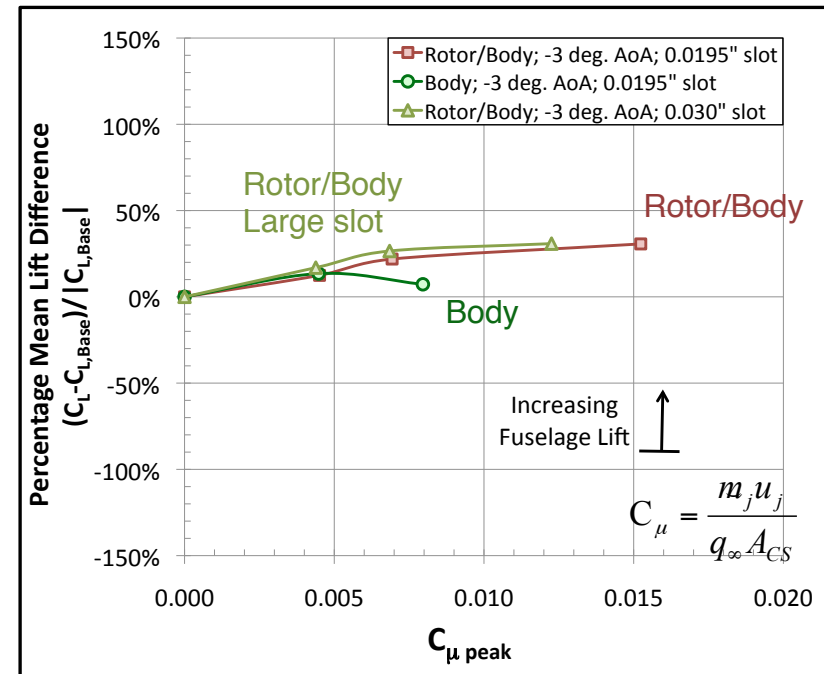
Fuselage Drag Reduction via Active Flow Control



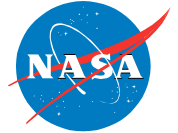
CFD Drag Performance



CFD Lift Performance



Turbulence Model Assessment for Rotorcraft Flows



- Most rotorcraft RANS computations use fixed-wing turbulence models (TM) >> Difficulties
- Effect of TM on rotorcraft flows largely unexplored
- Objective: Assess effect of TM on rotorcraft flows
- Study guidelines:
 - OVERFLOW flow solver
 - Hover & forward flight conditions
 - Two geometries: XV15, UH60
 - Near body (NB) & off body (OB) grids treated independently
 - NB & OB viscous terms activated independently
- Example results at right
 - Grid size: NB=19x10⁶, OB=28x10⁶
 - NB TM = Spalart-Almaras (SA)
 - NB viscous = RANS
- High levels of eddy viscosity (right) diffuse flow structure > large errors in FM

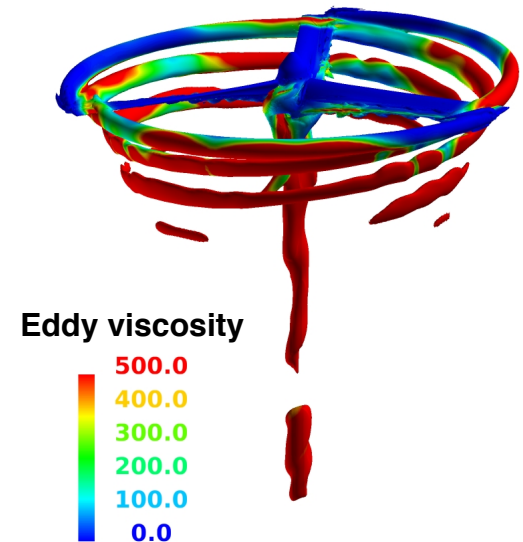
Iso-surface of vorticity colored by eddy viscosity

Inviscid OB



OB grid:
SA (source term OFF)
Viscous terms OFF
FM = 0.777

Fully RANS

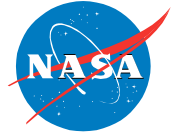


OB grid:
SA (source term ON)
Viscous terms ON
FM = 0.730

POC: Tom Pulliam, NASA Ames

Subsonic Rotary Wing Project

Turbulence Model Assessment—Grid Refinement



- XV15 in Hover
- $\theta=10^\circ$
- Spalart-Almaras
- 14 Revolutions
- $FM_{exp} \sim 0.77$

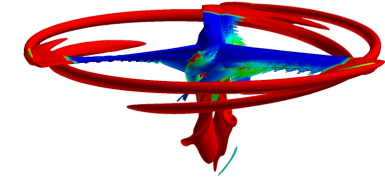
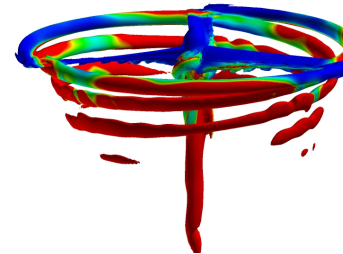
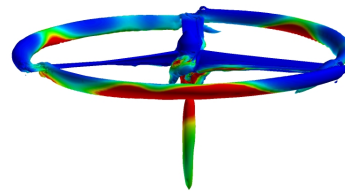
Grid ($\times 10^6$)	NB	OB	FM (Inv OB)	FM (RANS OB)
Coarse	5.3	4.4	0.785	0.752
Medium	19	28	0.777	0.730
Fine	80	207	0.772	0.715

Coarse grid

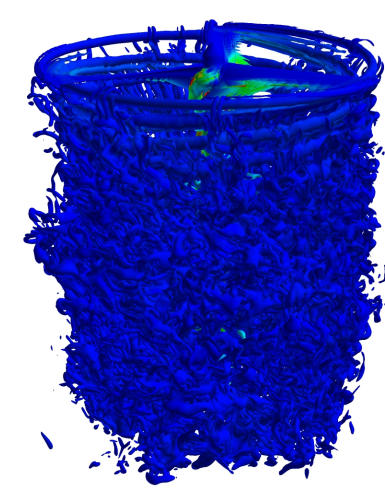
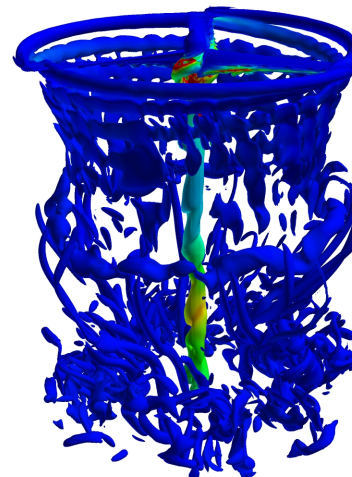
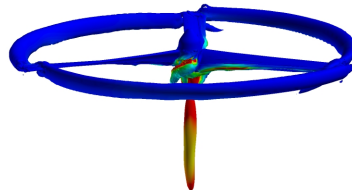
Medium grid

Fine grid

OB grid:
Source term OFF
Viscous terms OFF



OB grid:
Source term ON
Viscous terms ON



Iso-surface of vorticity
colored by eddy viscosity

RED ~ High

Blue ~ Low

Turbulence Model Assessment—UH60A Rotor

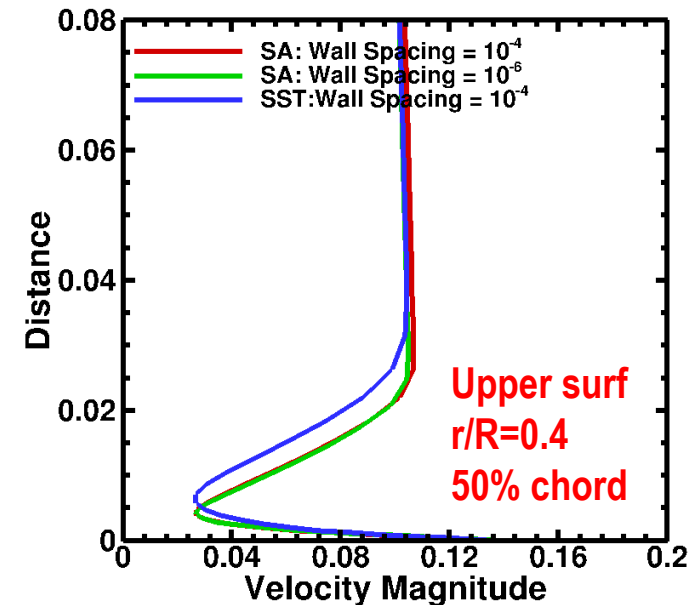


Hover results

- OVERFLOW with 5th O convection in OB, 2nd O time
- Isolated rotor with no trim tab
- Aeroelastic deflections based on exp measurement
- $M_{TIP}=0.65$, $\theta=10.5^\circ$

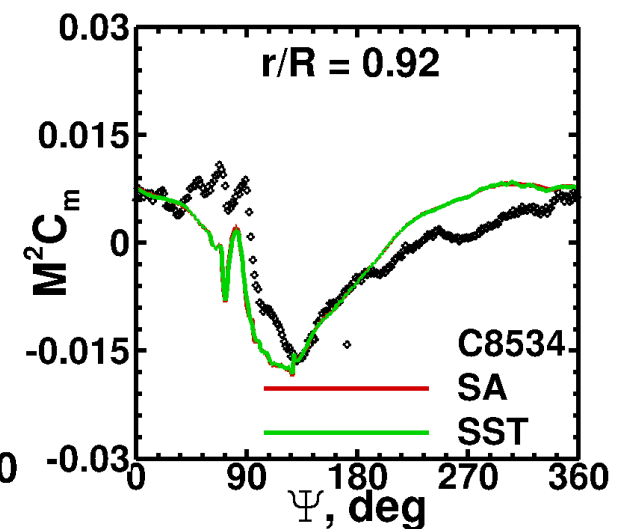
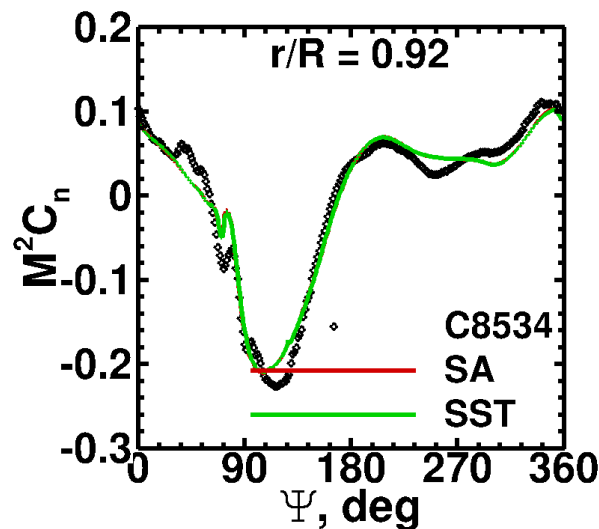
Model	FM	OB turb model options
SA-DES	0.7571	Hybrid RANS/LES
SA	0.7578	Source terms OFF, Inviscid
SST	0.7612	Source terms OFF, Inviscid
SA	0.7557	RANS
SST	0.7627	RANS

Boundary layer profile comparisons



Forward flight results

- OVERFLOW/CAMRAD II, loose coupling
- High Speed Flight Counter (C8534: $M_\infty=0.236$, $\mu=0.368$)
- SA and SST TM models



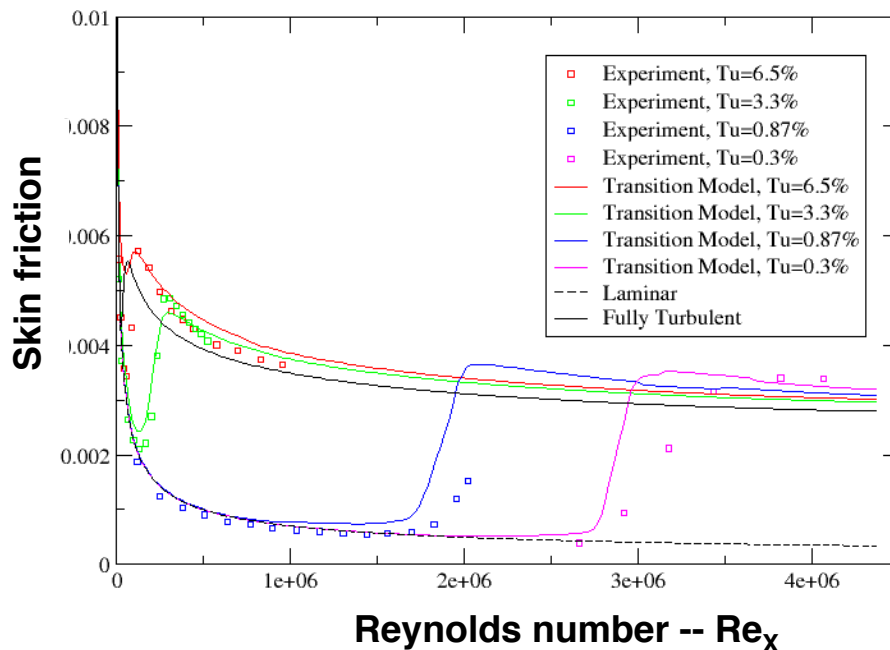
Rotorcraft Transition Modeling--Future



- Langtry-Menter transition model incorporated into OVERFLOW
 - Improves accuracy for cases with laminar-to-turbulent transition
 - Future effort: Include/evaluate Langtry-Menter model for rotorcraft flows to improve rotor blade stall prediction

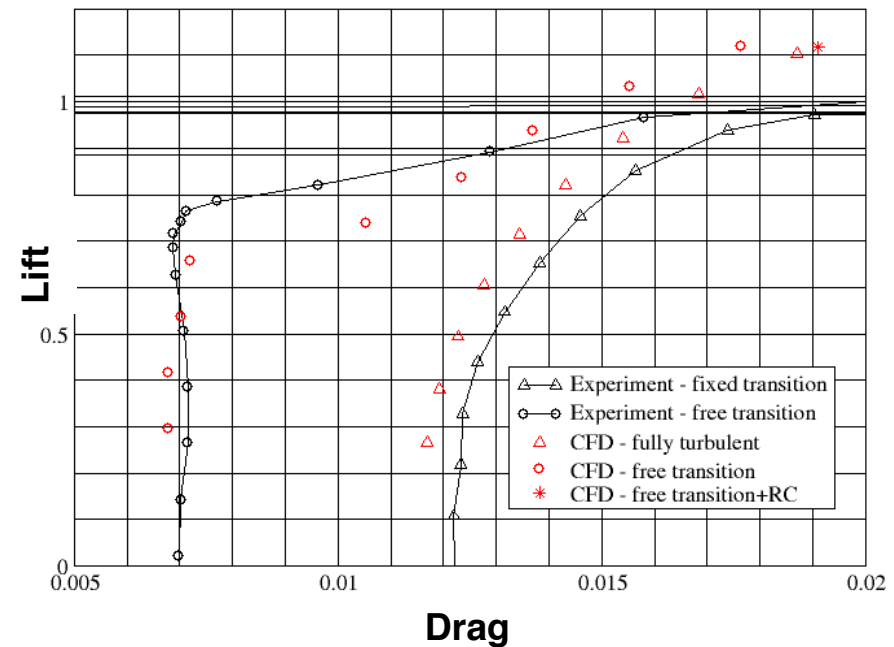
Flat plate skin friction

Different free-stream turbulence levels illustrate effect of Langtry-Menter transition model

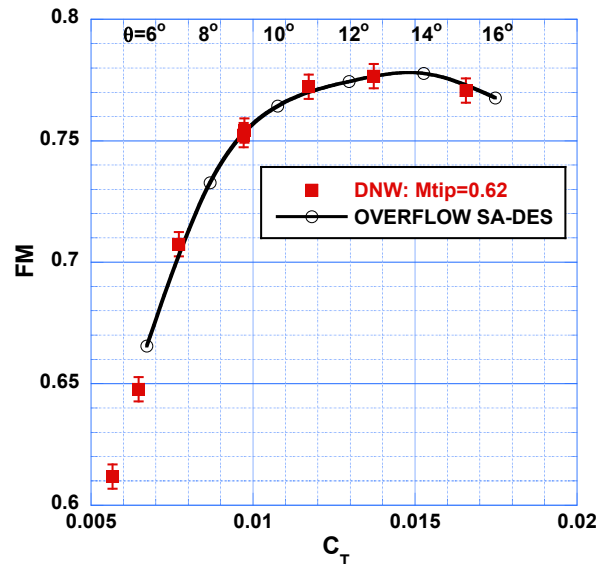


S809 airfoil drag polar

Comparisons between transitional and fully turbulent simulations.



Simulation of V22 Rotor System in Hover

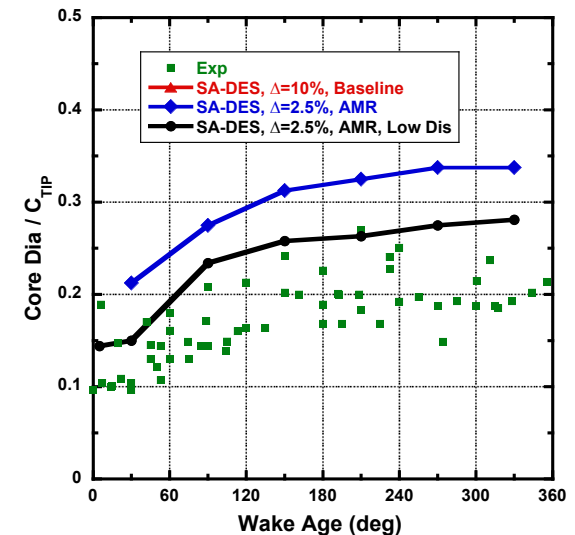
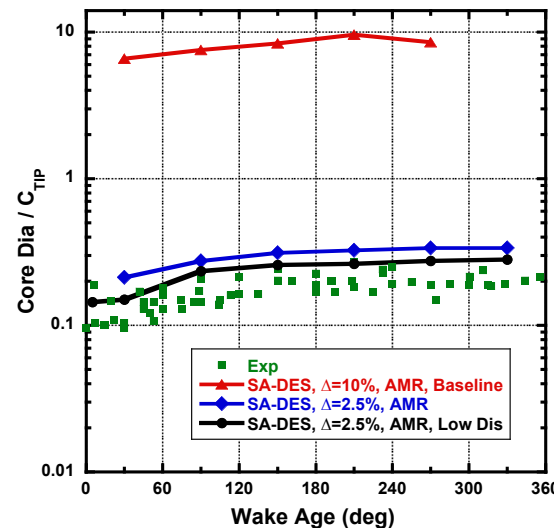
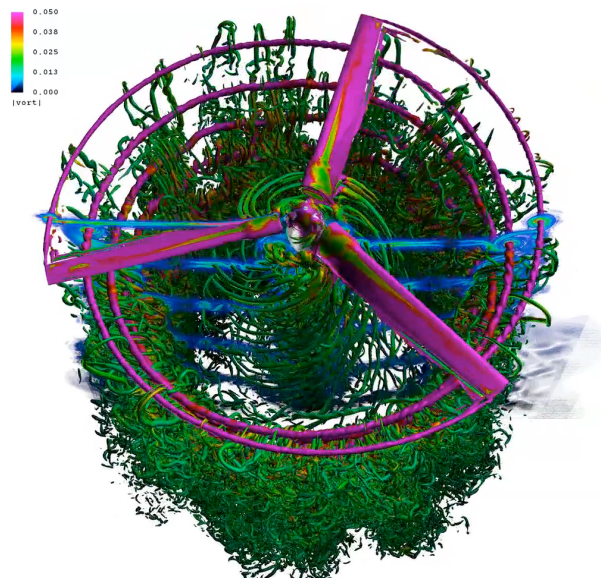


FM within Experimental Error

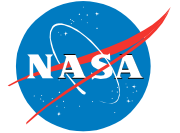
- Improved body resolution
- 5th-order spatial accuracy (OB convective terms)
- Detached Eddy Simulation (DES)

Adaptive Mesh Refinement

- Vortical worms produced due to blade wake shear-layer entrainment into vortex cores
- Prediction of vortex-core diameter growth more closely agrees with experiment
- Reduced dissipation



Simulation of UH60 Rotor System In Forward Flight



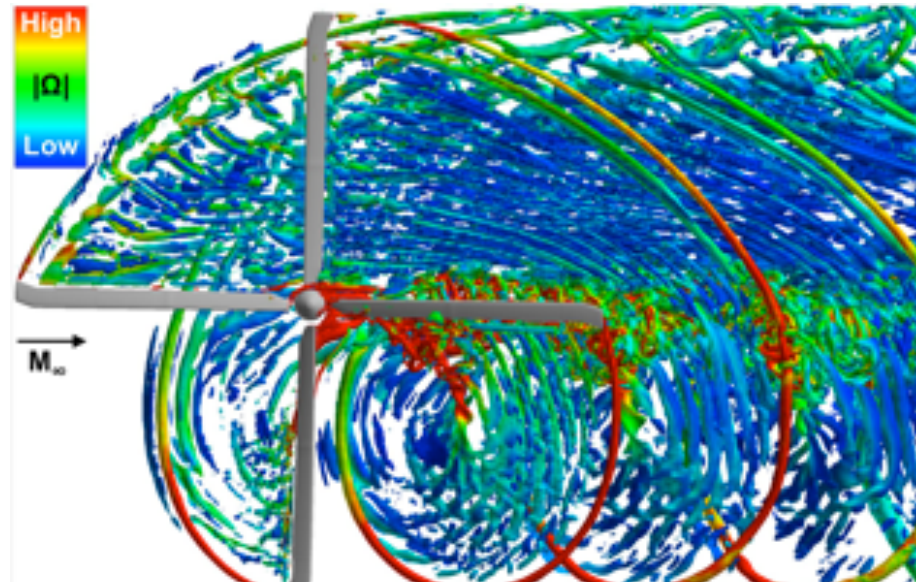
Baseline

- Flight Counter C8534 (High-Speed Case)
 - $M_\infty = 0.236$
 - $\mu = 0.37$
- Uniform spacing in off body grid: $\Delta = 10\% C_{tip}$

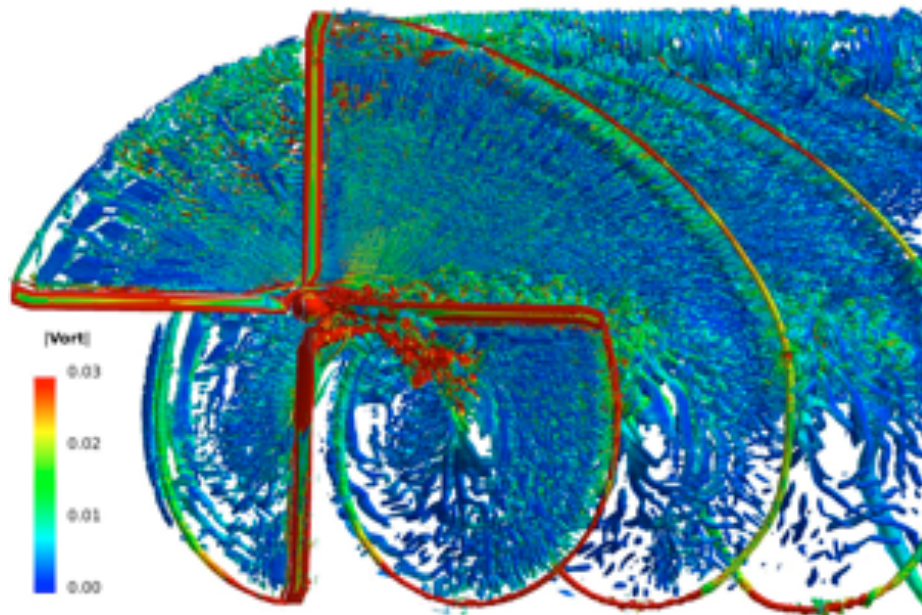
Adaptive Mesh Refinement (AMR)

- Three-level AMR used for off body grid:
 - $\Delta, \Delta/2, \Delta/4 = 10\%, 5\%, 2.5\% C_{tip}$
- Improved resolution of vortex core size
- Improved resolution of wake shear layer

POC: Neal Chaderjian, NASA Ames



**Baseline
Wake Grid
69x10⁶ Pts**



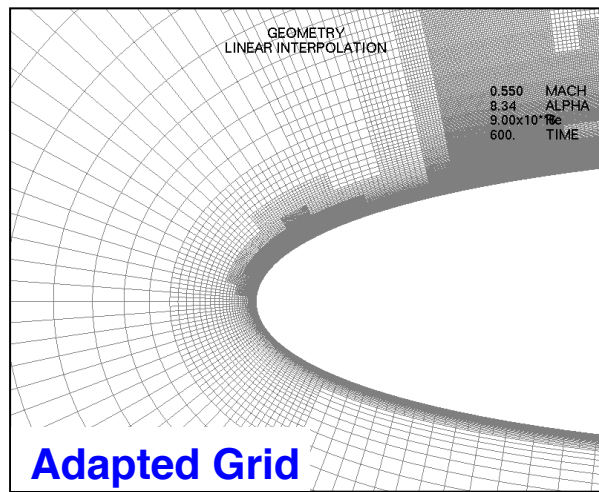
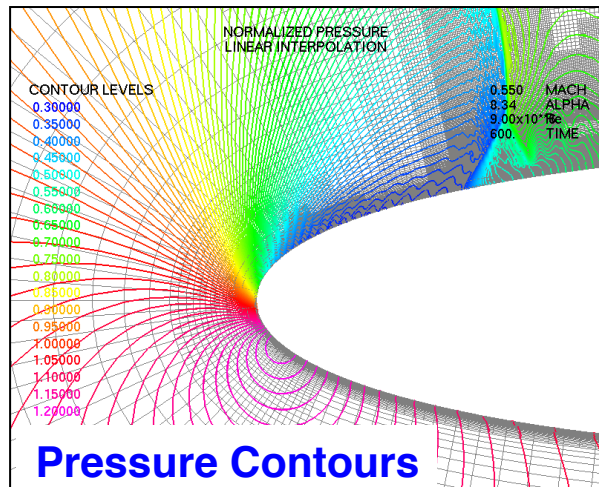
**AMR
Wake Grid
465x10⁶ Pts**

Near-Body Adaptive Mesh Refinement (AMR)

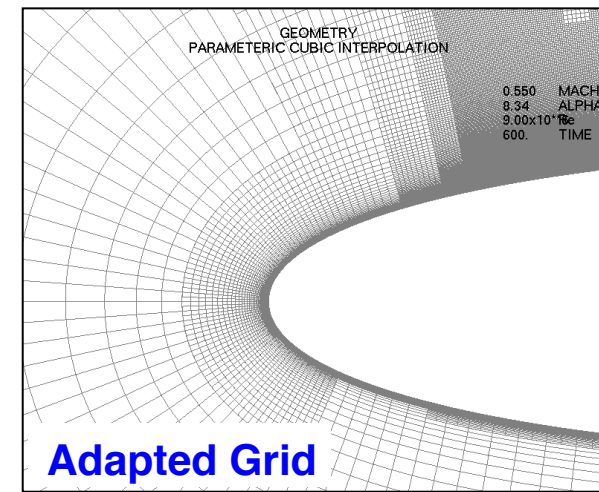
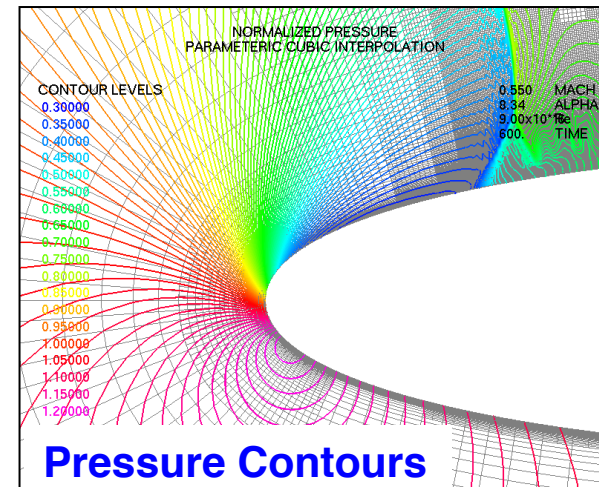


Cubic Interpolation Used to Avoid Oscillations Due to Faceted Surface Representation

Bilinear Interpolation

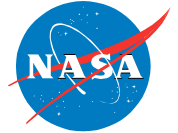


Cubic Interpolation



POCs: Pieter Buning, NASA LARC, Tom Pulliam, NASA ARC

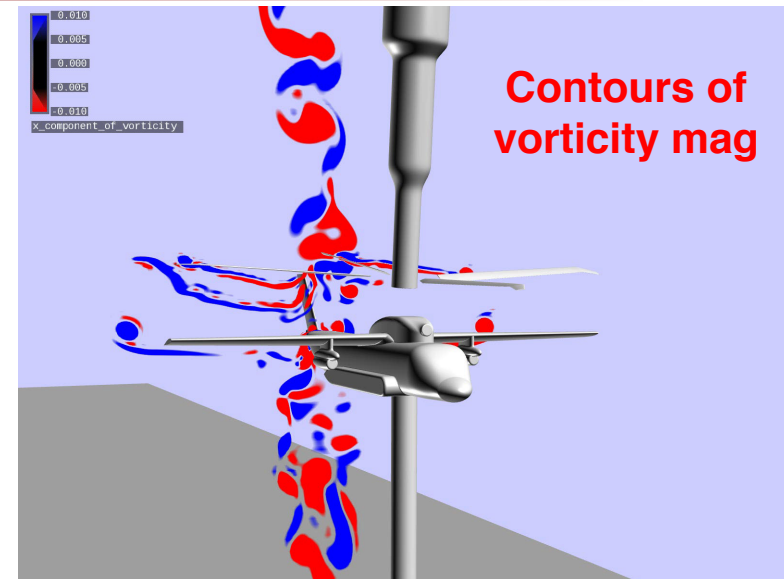
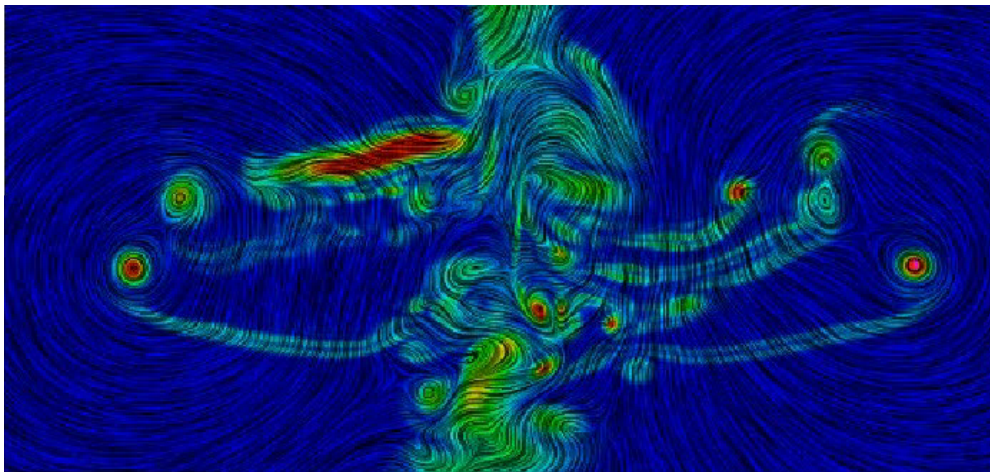
Heavy Lift Slowed-Rotor Compound Helicopter Flow Computations



OVERFLOW2 computations

- 5th O convection terms in OB, 2nd O time
- SST turbulence model
- Structured grid (113×10^6 points)
- Test performed in LaRC 14x22-ft subsonic tunnel
- Tunnel ceilings, support structure modeled
- Rotor radius = 0.8966m with non-uniform twist and tapered planform
- $\mu=0.54$, $M_\infty=0.21$

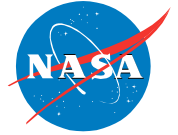
Vorticity contours superimposed on PIV plane with texture mapping



Surface flow



Isolated Rotorblade Flutter Computations



Codes utilized

- OVERFLOW2.2
- MODFLU (U-g method)

Coupling Approach

- Lagrange equations
- Frequency domain
- UNIX script
- RUNMOD using MPIEXEC

Geometry

- NACA0012 isolated blade

Grid

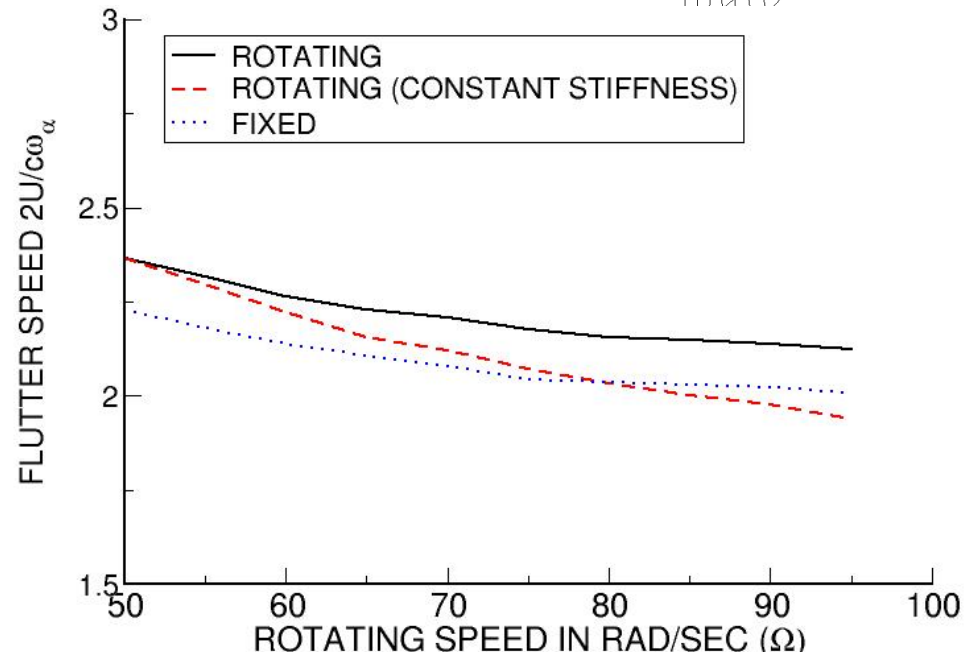
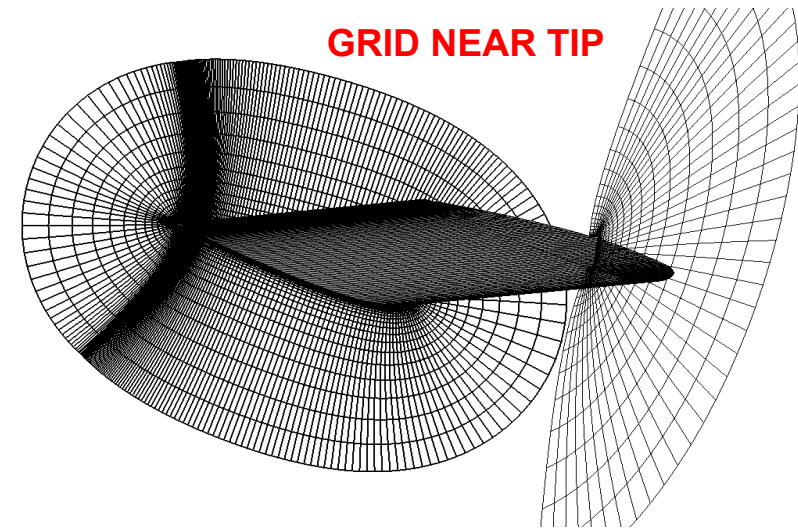
- 1.8×10^6 points

Modes

- Bending
- Torsion

Computational cost

- Flutter Boundary in 24 hrs using 1000 cores



POC: G. Guruswamy, NASA Ames

